DESIGN AND PERFORMANCE OF BITUMINOUS FRICTION COURSE MIXES

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ABSTRACT

Analysis of performance data from 2 major experimental field projects carried out in Ontario to develop bituminous friction course mixes with improved texture and friction characteristics are presented. The newly developed mixes maintain excellent surface texture and provide longer lasting skid resistance characteristics.

Design principals, construction and subsequent performance characteristics of these skid-resistant pavement surfaces are discussed. Aggregate properties, gradations and mixture characteristics which produce and maintain optimum texture levels with Ontario materials are identified. Mixes within such gradation boundaries were found not only to maintain superior texture qualities and friction levels but also to require less asphalt cement, when compared with conventional asphalt surfaces. The new friction course mixes use normal paving grade asphalts and require no special additives or fillers.

Use of the new friction course mixes for rehabilitation of pavements with low friction levels, and experiencing a high rate of wet weather collisions has produced substantial reductions in accidents. An average of 54% reduction in wet and a 29% reduction in total collisions were obtained after treatment at eight black spot freeway locations. Treatment at five black spot signalized highway intersections produced an average of 71% reduction in wet and 46% reduction in total accidents.

As a result of this work, the Ontario Ministry of Transportation and Communications implemented a policy which specifies the use of the new friction course mixes for new construction and resurfacing projects for all main highways. The new surface mixes are also used for rehabilitation at locations other than main highways, where excessive numbers of wet pavement collisions occur.

1. HISTORY OF SKID RESISTANCE DEVELOPMENTS IN ONTARIO

Pavement skid resistance research in Ontario started in 1962 utilizing the British Portable Skid Tester (1). Early efforts were primarily directed toward developing high-speed friction measuring capabilities and developing techniques to evaluate pavement textures. In 1967, organized high-speed skid testing started with a Ministry-built Brake Force Trailer meeting the ASTM 274 requirements (2), and in 1970 the Schonfeld's Photo-Interpretation technique for pavement texture classification (3-5) was introduced.

In the mid 1970s, considerable attention was given to the construction and maintenance of skid-resistant pavements so that wet weather accidents would be reduced and kept to minimum practicable levels. An extensive transverse grooving program on slippery concrete pavements was introduced (6,7), as were procedures for the erection of "Slippery When Wet" signs and the posting of wet pavement advisory speed limits at highway locations where more than one-third of the accidents were occurring under wet conditions. In addition, two major experimental projects were carried out to develop alternative bituminous surface course mixes with improved texture and friction characteristics for new construction. In 1974, seventeen test mixes were constructed on a section of the Highway 401, Toronto By-Pass to evaluate improved surface mixes for heavily-trafficked freeways and main highways (8,9). Seventeen other test mixes were constructed on Highway 7, near Lindsay, in 1978, to develop improved surface mixes for lower traffic volume highways (10). Each of the experimental projects included both types of dense and open-graded mixes and evaluated a variety of aggregate types. Results from the test roads provided an excellent data base for examining the effects of traffic, mix properties, aggregates, etc., on skid resistance.

It is the purpose of this report to review Ontario's experience with the design, construction, and performance of these skid resistant mixes over the past 7 years and to present data on their effectiveness in terms of accident reductions observed after resurfacing at highway locations experiencing excessive rates of wet pavement accidents.

2. SKID RESISTANT MIXES

A skid resistant surface must have sufficient microtexture, or harshness, and sufficient macrotexture, or stone projections.

Figure 1 shows a pavement surface profile and texture parameters as defined by Schonfeld (3,4). Pavement surface microtexture is a function of the harshness of the micro-projections on matrix surfaces as well as the harshness of the macro-projection surfaces. Macrotexture is a function of stone macro-projections physical properties such as height, width and angularity as well as density of such macro-projections on the pavement surface.

The role of the macrotexture is to break up the water film and to provide drainage channels so that most of the bulk water can be drained from the contact area between the rolling tire and the pavement surface. The microtexture allows penetration of the remaining thin film of water on the roadway surface. Good friction levels can only be obtained with adequate harshness or microtexture on the pavement surface. This is a desired property at all speeds. Adequate macrotexture will limit the drop in friction levels as vehicle speed and/or water thickness on the pavement surface increases.

Microtexture may be obtained using aggregates with high polish resistance, which show differential polishing and/or microtexture regeneration characteristics (11-13). Attainment and maintenance of macrotexture stone projections on the pavement surface are influenced by aggregate size, shape, gradation, type and composition, hardness, and resistance to wear (9-12).

3. SELECTION OF COARSE AGGREGATE IN FRICTION COURSE MIXES

Both macrotexture and microtexture qualities required for good wet surface friction characteristics are influenced by the quality, quantity, and gradation of the coarse aggregate in the mix. To ensure attainment of adequate texture and friction levels, many countries, particularly in Europe and Japan, use quality specifications or guidelines related to polished stone value

(PSV), aggregate abrasion value (AAV), texture depth, and minimum skid resistance levels as indicated in Table 1. Table 2 shows the PSV and AAV requirements developed by the Transport and Road Research Laboratory (TRRL) in England for various truck traffic (14). As commercial traffic increases, the requirements for aggregate polish and abrasion resistance also increase.

In Ontario, results from both the Highway 401 and the Highway 7 test sections confirm that coarse aggregates with higher PSV's produce mixes which maintain higher friction levels. This is demonstrated in Figure 2 for both heavy and moderate traffic conditions. The two mixes from Highway 401, shown in Figure 2, have been exposed to extremely heavy traffic conditions. Over a 5-year testing period, accumulated total traffic amounted to approximately 25 million vehicles of which 7 million were commercial trucks. The Highway 7 test at Lindsay has an average annual daily traffic (AADT) of 5500, of which 12% are heavy commercial vehicles.

Of particular interest is the low polished stone value of the traprock aggregate (PSV = 46). This value indicates the material will ultimately polish to a degree equivalent to, or only slightly better than, some limestone aggregates. The traprock aggregate is very hard, fine-grained, dark in colour, and 100% crushed material. According to the TRRL specifications, the traprock would not be permissible to use on heavy-trafficked facilities such as the Highway 401 Toronto By-Pass with commercial vehicles equal to 3740/day in the driving lane. However, mixes with 100% traprock materials such as that illustrated in Figure 2 have been used satisfactorily in Ontario on highways with very heavy traffic for a number of years. The satisfactory skid performance of the traprock mixes may be attributed to the excellent abrasion resistance of the traprock material (AAV = 2). The traprock aggregates tend to maintain angularity under severe traffic conditions and in turn provide and maintain sharp, angular, macrotexture projections on the pavement surface and acceptable overall skid resistance levels.

It appears that PSV should be considered side-by-side with aggregate ability to withstand abrasion and maintain angularity.

Maintenance of angular macrotexture stone projections on the pavement surface is essential in providing good friction levels for high speed traffic. Stones with moderate PSV but high abrasion resistance such as the traprock materials appear to provide satisfactory skid resistance performance under extremely heavy traffic conditions.

Blending of a better friction quality coarse aggregate, i.e. with higher PSV, in a mix can yield significant improvements in skid resistance. Figure 3 provides a comparison between the skid resistance performance of 4 mixes from the Highway 7 test. In the dense-graded friction course (DFC) mix, the coarse aggregate is a 1:1 blend of local limestone and imported igneous materials. This mix provides superior skid resistance levels in comparison with the 2 mixes which contain 100% limestone coarse aggregate. Its skid resistance is as good as the standard heavy duty HL1 mix which incorporates 100% traprock coarse aggregate and local fines. This DFC mix with the coarse aggregate blend is of particular interest because of its apparent economic advantages, in comparison with the standard HL1 mix; it utilizes higher percentage of local materials and requires less asphalt cement.

4. COARSE AGGREGATE CONTENT IN THE MIX

An important finding of the Highway 401 Toronto By-Pass test is that mixes with higher stone content maintained better surface textures than traditional mixes with 45% stone. Figure 4 shows the change in macrotexture depth and density (as measured by the Photo Interpretation Method) with pavement age for two mixes containing 45% and 55% traprock coarse aggregate (i.e. Ret. #4). The fine aggregate in both mixes is a blend of sand and limestone screenings. The superiority of the mix with 55% stone content is quite clear. It provided and maintained a better texture depth and density of stone projections on the pavement surface, whereas the macrotexture on the mix with 45% coarse aggregate virtually disappeared after less than two years in service. Overall, the mix with 55% coarse aggregate provided approximately 4 skid numbers higher than traditional HL1 mix with 45% stone when tested under standard test conditions at 100 km/h.

Similar observations are also made for two steel slag test mixes containing 45% and 55% coarse aggregate (Figure 5). The skid resistance of the mix with 45% stone (Ret. #4) declined from SN_{100} of 48 initially to SN_{100} of 39 after 21 months in service. The skid resistance of the mix containing 55% coarse aggregate has shown no significant decline in its 21 months of service.

It appears that mixes with 55% coarse aggregate provide higher resistance to the immersion of stone projections into the matrix under heavy truck traffic conditions; they maintain better and longer lasting surface macrotexture. The use of mixes with such high stone content also has economic advantages, mainly due to the reduced asphalt content required. As shown in Table 3, the stonier mixes use approximately 10% less asphalt cement than is used in traditional mixes which contain 45% stone content.

Results of laboratory testing on mixes with various coarse aggregate content in the U.K. appear to confirm our findings with the stonier mixes. Fabb and Heyes (15) found the optimum stone content for deformation resistance to be approximately 55% of the total mix when crushed coarse aggregate is used. In Japan (16), the use of such stonier asphalt mixes is prompted due to its excellent skid resistance characteristics and the higher resistance to rutting, particularly on heavily trafficked routes.

One last observation concerns sand mixes containing no or small amounts of coarse aggregate. The Highway 401 mixes included 4 sand mixes with coarse aggregate percentages ranging between 9 and 30%. All the mixes contained traprock coarse aggregate and traprock screenings fines. Such mixes produce good microtexture, but little macrotexture on the pavement surface. They provide reasonably good levels of skid resistance when tested under standard conditions with the brake force trailer, but tests with the MU-Meter showed these mixes to exhibit a significant decline in skid resistance under conditions of moderate or heavy rain (Figure 6). Such mixes would provide a satisfactory surface texture only for low speed traffic. In contrast, as indicated in Figure 6, high stone content mixes such as the open-graded (OFC) and the dense-graded (DFC), which also contain 100% traprock,

retain a high-level of skid resistance during particularly adverse conditions such as heavy rain and light snow/slush on the pavement surface.

5. SELECTION OF FINE AGGREGATE IN FRICTION COURSE MIXES

5.1 Heavily-Travelled Pavements

Maintenance of adequate texture levels and skid resistance on heavily-travelled highways depends not only on the quality of the coarse aggregate in the asphalt mixture but also on the quality of the fine aggregate in the mix. Under heavy traffic conditions, such as those on the Highway 401 Toronto By-Pass, the fine aggregate plays as important a role as coarse aggregate in achieving and maintaining skid resistance. This has been clearly demonstrated by the Highway 401 test mixes.

All test mixes on the Highway 401 test containing a blend of sand and limestone screenings fine aggregate were characterized by a sharp decline in skid resistance in their early service life. In contrast, all successful mixes contained premium quality crushed fine aggregate such as traprock and steel slag screenings. Figure 7 presents texture measurements for 3 test mixes. Macrotexture depth for test mix number 10, which contains a blend of sand and limestone screening fine aggregate, declined rapidly and almost ceased to exist during the first year in service. This is mainly due to compaction of the bituminous mix under traffic, resulting in impressment of the coarse aggregate particles into the matrix of the mix. Under the same testing conditions, mixes 9 and 13 with slag and traprock screenings fine aggregate provided and maintained reasonable macrotexture depth, macrotexture density, and good overall levels of skid resistance.

The above finding triggered, in 1976, a skid resistance survey for HL1 mixes in service. Over 50 contract locations were tested at highways where AADT was 5000 vehicles or greater per lane per day. The results are shown in Figure 8. It was found that the fine aggregate in 93% of deficient pavements is predominantly sand and in 90% of satisfactory pavements is predominantly crushed screenings.

The use of hard, harsh and angular fine aggregate appears to provide a number of advantages:

1. increased aggregate interlock causing a significant increase in Marshall stability for such mixtures. This provides high resistance to impressment of coarse aggregate, under heavy truck traffic, into the matrix of the mix;

2. increased harshness of the pavement surface due to angular and harsh pavement matrix;

3. increased macrotexture depth and density of stone projections on the pavement surface by the protrusion of the coarse aggregate particles from the matrix.

In summary, for heavily-trafficked freeways and main highways with a large numbers of truck traffic, it is essential that surface course mixes contain prime quality (hard, harsh, and angular) coarse and fine aggregates so that adequate texture and skid resistance levels can be maintained.

5.2 Moderate and Low Traffic Pavements

For moderate traffic volume highways, surface texture and skid resistance of asphalt mixes depend primarily on the quality of the coarse aggregate in the mix. Results from the Highway 7 test indicate that mixes with similar coarse aggregate (i.e. in type and in percentage in the mix) provide essentially similar skid resistance levels regardless of the type of fine aggregate in the mix. For example, the highest skid resistance values were obtained with 4 test mixes containing igneous coarse aggregate. Two of these mixes contained local limestone screenings and two contained igneous screenings fines (mixes 1 & 6 and 11 & 12 in Figure 9). The Lindsay mixes also indicated that replacing the sand fines with a blend of sand and limestone or sand and igneous screenings, or 100% limestone screenings, failed to provide significant skid resistance improvements (mixes 7, 8, 9, 14 & 15).

It appears that, for moderate and low traffic conditions, skid resistance levels (SN_{80}) of bituminous concrete mixes are predominantly influenced by the type of coarse aggregate in the mix. The role of fine aggregate is significantly less apparent than in the case of heavily-travelled highways.

6. AGGREGATE GRADATIONS FOR FRICTION COURSE MIXES

The MTC gradation requirements for coarse aggregate used in conventional surface mixes (HL1 and HL3), Dense Friction Course mixes (DFC), and Open Graded Friction Course mixes (OFC) are shown in Table 4. Nominal size for coarse aggregate is 13.2 mm (1/2") for conventional and DFC mixes and 9.5 mm (3/8") for OFC mixes. Only crushed screenings fine aggregate is acceptable for Friction Course mixes. Screenings are washed for use in the OFC mixes and utilized unwashed for the DFC mixes. Gradation requirements for fine aggregate in conventional, DFC and OFC mixes are shown in Table 5.

Based on the performance of the various Friction Course mixes on Highway 401 and Highway 7 recommended target gradations for total aggregates in OFC and DFC mixes have been developed as shown in Figure 10. Over the period from 1978 to 1980, MTC constructed many pavement friction course sections meeting the above target gradations with excellent results. Mixes were placed at highway locations with extremely heavy traffic volumes, e.g. Highway 401, Toronto By-Pass, and Highway 417, Ottawa, as well as at highway locations with moderate traffic e.g. Highway 401, Kingston, and Highway 7, Lindsay. Such mixes produce excellent surface textures and maintain superior overall friction levels. As previously shown, these stonier mixes demand less asphalt cement and thus have additional economical advantages over normal mixes. They also maintain high levels of skid resistance during adverse weather conditions such as heavy rain or light snow/slush on the pavement surface.

7. MIX DESIGN

The DFC mixes are designed in almost the same manner as conventional mixes. The MTC mix design method utilizes the Marshall

equipment (18). The briquettes are compacted mechanically with 60 blows per side of a Marshall hammer. The most significant difference is that particular emphasis is placed on visual evaluations of loose and compacted mix samples. The results of both the visual assessments and the Marshall mix properties determine the designed asphalt content in the mix.

DFC mixes containing 100% crushed screenings fine aggregate are characterized by high Marshall stability values, usually a minimum of 9000-10 000 N (2000-2250 lb). They are also characterized by relatively higher voids "in the pavement" resulting from difficulties in compacting these dense, high stone content mixes in the field (10). With maximum efforts, it is normal to obtain only 90% compaction in the field with these high stability, high stone content mixes. For this reason, and to insure durability, the DFC mixes must be designed to have well-coated aggregate particles. MTC practice is to design these mixes with a rich to very rich asphalt appearance. In many instances visual assessment of loose and compacted mix samples becomes the decisive factor in selecting the designed asphalt level. Examples of Marshall design values for DFC mixes are shown in Table 6. For comparative purposes, design specifications for traditional HL1 and HL3 surface course mixes call for an asphalt content of 5-7% and design voids of 2-4%.

For design of OFC mixes, Marshall testing is carried out, but once again visual evaluations of loose and compacted mix samples would greatly influence the selection of the designed level of the asphalt binder. OFC mixes are also designed to have well-coated aggregates and a rich to very rich asphalt appearance.

Examples of Marshall design values for various OFC mixes are given in Table 7.

Gulf Canada Limited has developed a computer program which enables the mix designers to determine optimum and most economical blends of aggregate components for dense-graded mixes (17). From gradations and cost for each available coarse and fine aggregate, the program calculates all possible blends

which would result in a mixture meeting specified total target gradation limits. The program also calculates the relative mix stability, VMA and total aggregate cost for each alternative mixture and prints out a listing of all possible combinations. This program provides an excellent design tool which can almost instantly identify the most economical blends for dense graded mixes including friction courses. Marshall mix designs are then carried out on selected aggregate blends in the normal way.

8. CONSTRUCTION OF FRICTION COURSE MIXES

Details on construction of DFC and OFC mixes are given in Refs. 8, 10. Mixing temperatures for OFC mixes range between 121-135°C (approx. 250-275°F). It is the MTC practice to maintain mixing temperature for OFC mixes below 149°C (300°F) to prevent asphalt runoff. Mixing temperature for DFC mixes range from 150°C to 165°C (approx. 300-325°F).

Placing of the OFC and the DFC mixes is carried out with conventional equipment, i.e. a paver equipped with a vibratory screed. Compaction is carried out immediately after the mix is placed, using only a 10-ton steel drum roller on the OFC mixes and both the steel and rubber-tired rollers on the DFC mixes. The OFC mixes are constructed 25 mm (1") in thickness and the DFC mixes are placed 38 mm (1 1/2") thick.

9. PERFORMANCE OF FRICTION COURSE MIXES

This section provides additional information on field performance of both OFC and DFC mixes. Testing results on pavement core samples, pavement permeability, skid resistance, and noise characteristics as well as winter maintenance and performance are discussed.

9.1 Pavement Core Samples

Pavement core samples taken from the wheel tracks in the driving lane from both the Highway 401 and the Highway 7 tests showed initial pavement voids for OFC mixes ranging between 10% and 20%

(9,10). Initial pavement voids of 15% in these open-graded mixes are desired.

On the Highway 401 Toronto By-Pass, further coring after approximately 4 years indicated pavement voids declined on average, by 3.7%. There was no significant difference in results from cores taken from the wheel paths and centre of lane. On the Highway 7 tests on the OFC mixes indicated that "the voids in the pavement" decreased by an average of 1.3% during the first 13 months in service.

For the DFC mixes, initial pavement voids were found to range between 9 and 15%. The high voids in the pavement illustrate the problem of compacting these high stone content/high stability mixes in the field. Subsequent testing, however, showed a reduction in the pavement voids in both cases of heavy and moderate traffic. On the Highway 401 Toronto By-Pass, the DFC mixes experienced an average reduction of 3.65% in the pavement voids during the first 18 months after construction. On Highway 7 the reduction in pavement voids averaged 0.9% in the first 13 months in service.

It should be noted that initial pavement voids in conventional dense graded surface mixes (HL1 and HL3) would normally range between 7 and 8%.

9.2 Pavement Permeability Tests

In situ permeability tests have also been carried out on the OFC and the DFC mixes on Highway 401 Toronto, and Highway 7 Lindsay (9,10). Testing results indicated high initial permeability obtained in all cases but subsequent measurements after 1, 2, and 4 years showed substantial permeability reductions.

Under the heavy truck traffic on the Highway 401, Toronto, the OFC mixes showed high permeability in the first 2 years after construction. During the next 2 years the mixes became considerably less permeable, with 3 of 9 locations showing permeability

readings in the impermeable range. The testing also showed a trend for the passing lane, where limited number of trucks travel, to retain its initial high permeability characteristics better than the centre and driving lanes. Under the moderate traffic conditions on Highway 7 at Lindsay, testing conducted one year after construction indicated the OFC mixes to maintain their original high permeability properties.

Test results on the various DFC test mixes on Highways 401 & 7 also indicated considerable reductions in pavement permeability within the first 2 years in service. All DFC mixes on the Highway 401 test provided 4-year permeability readings in the impermeable range.

9.3 Pavement Skid Resistance and Noise Characteristics

Figure 11 shows the high-speed skid resistance (SN_{100}) vs. accumulated traffic volumes for some selected mixes from the Highway 401, Toronto By-Pass test. Two DFC mixes containing traprock and steel slag coarse and fine aggregates, one OFC mix with traprock coarse aggregate and washed traprock screening fines, and a standard HL1 (control) mix which contains traprock coarse aggregates and a blend of sand and limestone screening fines. AS can be seen, the initial SN_{100} values obtained on the DFC and the OFC mixes are 9 to 15 skid numbers higher than that observed on the standard HL1 mix. Over the five years in service the OFC and the DFC mixes maintained significantly higher friction levels in comparison with the HL1 mix. With a total of approximately 24 million vehicle passes, 7 million of which were heavy commercial trucks, the skid resistance of the OFC and the DFC was close to or above the identified target friction level, whereas the skid resistance of the standard mix declined sharply below target values during the first year in service.

Both the DFC and the OFC mixes with high stone content are characterized by well-developed macrotexture of the surface. The texture and appearance of such mixes can be described as coarse, rugged and open in comparison to the fine, level and tight surface of conventional type mixes.

As previously indicated, the OFC and the DFC mixes also retain a high level of skid resistance during particularly adverse conditions such as heavy rain and light snow/slush on the surface (Figure 6). The performance of 2 OFC and 4 DFC test mixes in the Highway 401 experimental sections has been excellent. During the seven years in service these mixes have maintained high skid resistance levels and excellent overall performance.

The OFC surfaces also provide reduced tire-pavement noise levels. An earlier study (19) found the OFC mixes 3 dB(A) quieter than adjacent smooth concrete and 4 to 5 dB(A) quieter than a typical conventional HL1 mix. This study measured near-tire noise levels using a microphone mounted 152 mm from the road surface on a 1974 Ford LTD Sedan equipped with summer radial tires and operated at 100 km/h.

9.4 Winter Performance and Maintenance

The Ministry also carried out a study of the OFC and DFC mixes on the Hwy. 401 Toronto By-Pass to observe pavement performance during various winter storms and to determine whether or not more deicing materials were required to clear these coarse open textured mixes (21). Adjacent normal dense-graded asphalt surfaces and concrete pavements were included as control sections.

The observations extended over two winters and covered all types of winter storms with particular emphasis on freezing rain storms. It was found that:

1. The spinning of the sand and salt in such a way to cover all traffic lanes is the most effective way to clear OFC pavements. More salt was not required to clear OFC and DFC pavements.

2. Under the most storm conditions, the OFC and the DFC pavements appeared to provide the best friction levels.

3. The timing of salt applications with respect to freezing rain storms appeared critical for all pavement surface types. With spinning of the deicing materials, freezing rain storms presented no problems on the OFC and the DFC pavements.

10. BITUMINOUS SURFACE COURSE POLICY

As a result of this work the MTC, in 1978, introduced a new policy for bituminous surface course construction on freeways and other main highways in Ontario. The new policy specifies the use of OFC mixes on all urban freeway surfacing and the use of DFC mixes on other freeways and main highways carrying a traffic volume in excess of 5000 vehicles per lane per day. HL1 mixes are used on facilities with AADT ranging between 2500-5000 vehicles per lane per day.

Since the introduction of the new surface policy in 1978, a total of approximately 400 lane kilometres (250 lane-miles) of pavements has been constructed with OFC and DFC on the MTC system. For freeways and main highways only traprock and steel slag coarse and fine aggregates are acceptable for DFC mixes.

11. USE OF FRICTION COURSE MIXES FOR REHABILITATION AT BLACK SPOT HIGHWAY LOCATIONS

In 1978, procedures were also introduced which identified highway locations with high rates of wet pavement accidents (black spots). It was found that while the total length of identified black spots on the system presented only a fraction of percentage point (0.29%), they exhibited 26% of the total wet pavement accidents on the system (20). The study also found that wet pavement collisions on freeway and 4-lane black spots account for over 75% of the total black spot accidents.

The black spot improvement program provided an excellent opportunity to test the effectiveness of the new friction course mixes. Both the OFC and the DFC mixes were used for rehabilitation at such highway locations. The tentative friction guidelines shown in Table 8 have been used in establishing priorities

for treatment. Rehabilitation at some black spots included geometrics and/or other improvements as well as resurfacing as noted in the following sections.

11.1 Number of Accidents Before and After Treatments at Freeway Black Spots

Table 9 shows the number of wet and total accidents before and after resurfacing at 8 freeway locations treated during the period 1976 to 1978. Six locations are on Highway 401 Toronto By-Pass, one on Highway 401 near London and one on Highway 417 (Ottawa Queensway). Two years' accidents were considered before resurfacing, and 1, 2 and 3 years' accidents were considered after treatment for work done in 1978, 1977 and 1976.

Reductions in wet pavement accidents after resurfacing ranged between 17 and 73%. For all 8 locations combined, an average of 54% reduction in wet pavement accidents was obtained. Overall reduction in total accidents (i.e. wet, dry, snow and ice) was 29%.

An OFC mix was used on all the Highway 401 Toronto locations and a DFC mix was used at London on Highway 417. In all projects the surface coarse mix included traprock coarse aggregate and traprock screening fines, except on Highway 401 at London where steel slag coarse and fine aggregates were used. At Highway 417, rehabilitation included widening of the pavement from 2 to 3 lanes in each travel direction.

In all cases the old pavement was concrete. Resurfacing with the OFC and DFC mixes has approximately doubled the skid resistance levels.

It is interesting to compare the number of accidents on the treated portions of the Highway 401, Toronto By-Pass, with the accidents on the total length of the By-Pass (30 km or 19 mi.). During the period of observation, traffic volumes increased by approximately 25%, a number of geometric improvements were made, and in 1976 the speed limit was reduced from 112 km/h (70 mph) to 100 km/h (60 mph). In the five year period between 1975 and 1979

the total number of accidents on the 30 km section remained at relatively constant annual levels. The wet pavement accidents as a percentage of total accidents varied between 31 and 33% for the period between 1975 to 1977 and 24 to 26% for 1978 and 1979. It would appear that as more rehabilitation work is carried out at black spot locations on the by-pass, further reductions in the number and the percentage of wet to total accidents may be achieved.

11.2 Number of Accidents Before and After Treatment at Signalized Intersections

Table 10 gives the number of wet and total accidents before and after rehabilitation at five black spot signalized intersections treated in 1977 and 1978. An average of two years' accidents before, and one year after treatment were considered.

The reductions in wet pavement collisions after treatment ranged between 33 and 100%. Overall, for the five intersections combined, an average of 71% reduction in wet pavement accidents and 46% in total accidents was obtained.

Pavement skid resistance levels observed before and after treatment at various sites showed improvements between 13 and 20 skid numbers as measured by the ASTM skid trailer.

With one notable exception, treatment at all sites included resurfacing with a DFC mix. Traprock coarse and fine aggregates were used on Highway 7 and Highway 2, and steel slag coarse and fine aggregates were used on Highway 40 and Highways 2 and 4.

At Highway 3, treatment included retexturing of the pavement surface by cold planing using a CMI rotomill (7).

The old pavement in all cases was bituminous concrete. Major deficiencies included excessive polishing of coarse aggregates on the surface, wheel track rutting and surface contaminations by oil deposits at the intersections.

Treatment of black spot intersections appears most effective at the intersection of Highway 7 and Islington Avenue in Woodbridge. At this location rehabilitation included resurfacing with a DFC mix plus installation of an electronic, overhead, warning traffic sign with flashing lights at the top of the grade approaching the intersection. The sign operates in conjunction with the traffic lights at the intersection and reads "BE PREPARED TO STOP" when the amber or red lights are on. During the time prior to rehabilitation, this location had consistently shown high incidence of wet pavement accidents. During the first year after treatment, rehabilitation resulted in a 76% reduction in wet accidents and a 69% reduction in the total accidents at the intersection.

12. CONCLUSIONS

1. Both macrotexture and microtexture qualities required for good wet pavement friction characteristics are influenced by the quality and gradation of the aggregate in the asphalt mix. Mixes containing aggregates with higher PSV produce higher friction levels.

2. PSV should be considered side-by-side with aggregate abrasion characteristics particularly for high-speed traffic where maintenance of angular macrotexture stone projections on the pavement surface is essential in providing good friction levels. Stones with moderate PSV but having high abrasion resistance, such as the traprock materials in Southern Ontario, provide satisfactory skid resistance performance under extremely heavy traffic conditions.

3. Blending a higher PSV coarse aggregate in a mix can yield significant skid resistance improvements.

4. The use of a high percentage of crushed coarse aggregate in bituminous mixes appears to produce better and longer lasting surface textures and skid resistance levels. Such stonier mixes also have economical advantages, mainly because of less asphalt cement requirements. Sand mixes containing traprock screenings that produce good microtexture

but little macrotexture provide a reasonable level of skid resistance when tested under standard conditions with the brake-force trailer, but exhibit a significant decline in skid resistance under conditions of moderate or heavy rain. Such mixes would provide a satisfactory surface texture only for low speed traffic.

5. For very heavily-trafficked pavements with large numbers of trucks, use of prime quality (hard, harsh and angular) crushed coarse and fine aggregates is essential so that adequate texture and skid resistance levels can be maintained under such severe traffic conditions. For moderate traffic volumes, skid resistance levels of bituminous mixes are predominantly influenced by the type of the coarse aggregate in the mix. The role of the fine aggregate is significantly less apparent than that in the case of heavily-trafficked highways.

6. Performance analysis of various test mixes on Highway 401, Toronto, and Highway 7, Lindsay, identified target total aggregate gradation limits for dense and open-graded mixes. Mixes within such gradations produce excellent surface textures and maintain superior overall friction levels. They also maintain high levels of skid resistance during adverse weather conditions such as heavy rain or slight snow slush on the pavement surface. The Open Friction Course Mixes provide reduced noise levels.

7. Use of the new friction course mixes at highway locations which have low friction levels and experience a high rate of wet pavement collisions appears to produce substantial reductions in wet and total accidents.

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TABLE 1: Specifications for Pavement Friction in Europe and Japan (Ref. 14)

Country	Polished Stone Value (PSV*)	Macro-texture Depth (**)	Aggregate Abrasion Value (AAV*)	Min. Skid Resistance For New Pavements
Belgium	CS	CS		CS
Czechoslovakia				R
France	R	R		
Great Britain	CS	CS	CS	R
Federal Republic of Germany				R
Netherlands	CS	R		CS
Spain	CS			
Switzerland				CS
Japan				R

* British Stand. 812 or similar
** British Stand. Sand Patch Method or similar
CS = Contractual specifications
R = Recommendations or guidelines

TABLE 2: PSV of Aggregate Necessary to Achieve the Required Skidding Resistance in Bituminous Surfacings Under Different Traffic Conditions (Ref. 14)

Required Mean Summer Skid Resistance (SFC) 50 km/h	PSV of Aggregate Necessary Traffic in Commercial Vehicles Per Lane Per Day 250 or under	1000	1750	2500	3250	4000
0.30	30	35	40	45	50	55
0.35	35	40	45	50	55	60
0.40	40	45	50	55	60	65
0.45	45	50	55	60	65	70
0.50	50	55	60	65	70	75
0.55	55	60	65	70	75	
0.60	60	65	70	75		
0.65	65	70	75			
0.70	70	75				
0.75	75					
AAV	not greater than 12			not greater than 10		

TABLE 3: Mix Composition and Asphalt Content for Conventional and Stonier Mixes

Mix	Ret. #4	Pass #4	% AC by Wt of Mix	Remarks
HL1	45% Traprock	55% Blend of sand and limestone scr.	5.4	Test mix #1, 1974 Exp. Hwy. 401.
HL1	55% Traprock	45% Blend of sand and limestone scr.	4.8	Test mix #4, 1974 Exp. Hwy. 401.
DFC	45% Steel Slag	55% Steel Slag screenings	5.3	Test mix #7, 1974 Exp. Hwy. 401.
DFC	55% Steel Slag	45% Steel Slag screenings	4.8	Test mix #2 1978 Exp. Hwy. 401.

TABLE 4: MTC Gradation Requirements for Coarse Aggregates

Ministry Sieve Designation	Percentage Passing by Weight HL1 & HL3	DFC	OFC
13.2 mm (1/2")	100	100	100
9.5 mm (3/8")	50 - 73	50 - 73	95 - 100
6.7 mm (#3)	-	-	20 - 45
4.75 mm (#4)	0 - 10	0 - 10	0 - 10
75 µm (#200)	0 - 2	0 - 2	0 - 2

TABLE 5: MTC Gradation Requirements for Fine Aggregates

Ministry Sieve Designation	Percentage Passing by Weight HL1 & HL3	DFC	OFC
9.5 mm (3/8")		100	100
4.75 mm (#4)	100	85 - 100	85 - 100
2.36 mm (#8)	80 - 100	50 - 70	50 - 70
1.18 mm (#16)	55 - 90	25 - 50	25 - 45
600 µm (#30)	35 - 70	15 - 40	10 - 30
300 µm (#50)	15 - 40	10 - 30	0 - 20
150 µm (#100)	5 - 15	5 - 25	0 - 10
75 µm (#200)	0 - 5	0 - 17	0 - 3

TABLE 6: Examples of Marshall Design Values for DFC Mixes

Agg. Type in the Mix	% Ret. # 4	% Asphalt	% Voids	Flow 0.25 mm (.01")	% VMA	Stability N (lb)
Steel Slag	55	4.8	3.7	15.1	17.4	13608(3058)
Igneous	55	5.0	3.0	16.2	13.7	10564(2375)
Traprock	45	4.5	1.2	21.5	12.7	13900(3125)
Sandy Dolostone	60	4.8	2.0	15.1	11.9	10453(2350)
Limestone	55	4.5	1.7	20.3	11.9	9341(2100)

TABLE 7: Examples of Marshall Design Values for OFC Mixes

Agg. Type in the Mix	% Ret. # 4	% Asphalt	% Voids	Flow 0.25 mm (.01")	% VMA	Stability N (lb)
Steel Slag	65	5.2	5.6	17.9	16.0	8227(1850)
Igneous	65	5.3	6.5	13.6	17.7	6049(1360)
Traprock	65	5.0	8.4	11.7	20.1	8139(1830)
Sandy Dolostone	65	4.6	9.0	11.1	18.0	7784(1750)
Limestone	65	4.1	5.5	13.5	13.7	7784(1750)

TABLE 8: Tentative Guidelines for a Friction Classification System

Facility Type	Speed Limit km/h	Friction Level (SN) at Speed Limit Good	Borderline	Low
Freeways and main highways	100	>30	25 - 30	<25
2-lane and 4-lane	80	>31	27 - 31	<27
Intersections	80	>39	31 - 39	<31
	60	>44	36 - 44	<36

TABLE 9: Change in Accidents Before and After Resurfacing at Black Spot Freeway Locations

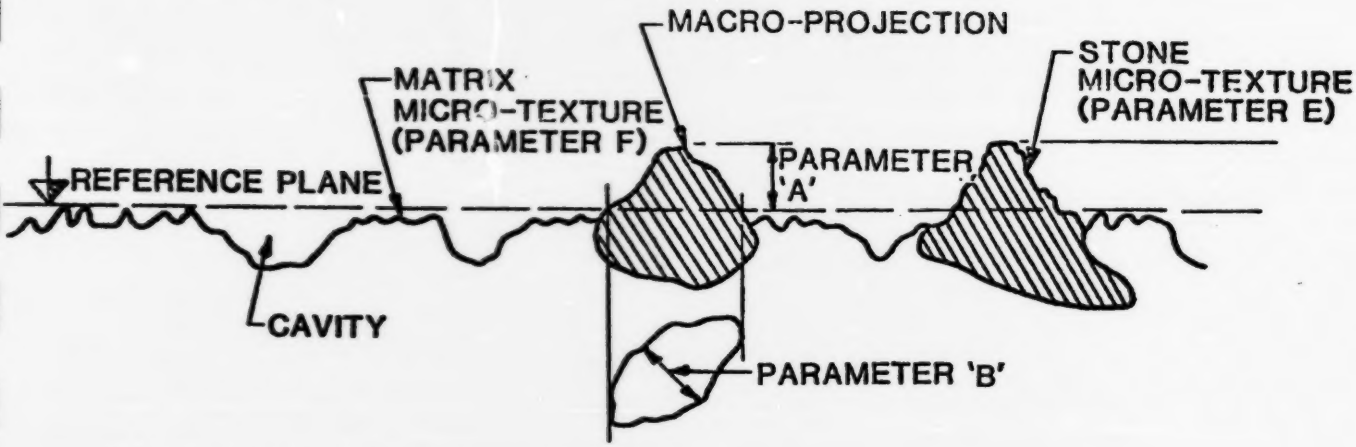
Location	Year of Treatment	Wet Accidents No.	Wet Accidents % Change	Total Accidents No.	Total Accidents % Change	Remarks
Hwy. 401, Toronto: Int 51A to Int 53 Express Lanes	1976	B 64 A 30	-53	B 220 A 173	-21	East & Westbound, 3 lanes each direction
Collector Lanes	1977	B 40 A 23	-40	B 155 A 118	-24	East & Westbound, 3-4 lanes each direction
Int 58 to Int 57 Collector Lanes	1978	B 7 A 2	-71	B 16 A 5	-69	Westbound, 3 lanes before & 4 lanes after treatment
Int 56 to Int 55 Collector Lanes	1978	B 22 A 10	-55	B 46 A 35	-24	Westbound, 4 lanes
Transfer Lanes at Int 56	1978	B 15 A 6	-60	B 26 A 15	-42	Westbound, 2 lanes AADT 17 000
Int 51A to Int 50 Collector Lanes	1978	B 30 A 25	-17	B 98 A 92	-6	Westbound, 3-4 lanes
Hwy. 401, London Int 19 to 1.1 km w'ly	1978	B 6 A 2	-67	B 13 A 7	-46	Only 2 Westbound lanes treated, WB AADT 9000
Hwy. 417, Ottawa St. Laurent Blvd. to Hurdmans Bridge	1977	B 73 A 20	-73	B 168 A 79	-53	East & Westbound, 2 lanes before & 3 lanes after treatment AADT 61 000 in both directions
Total		B 257 A 118	-54	B 742 A 542	-29	

B and A designate number of accidents "Before" and "After" resurfacing.

TABLE 10: Accidents Before and After Treatment at Black Spot Intersections

Location	Year of Treatment	Wet Accidents No.	Wet Accidents % Change	Total Accidents No.	Total Accidents % Change	Rehabilitation Type	Remarks
Hwy. 7 at Islington Ave.	1978	B 17 A 4	-76	B 35 A 11	-69	DFC mix with 100% traprock aggregate plus a warning traffic sign	4 lane undivided 6% grade AADT 27 000 only WB lanes (downgrade) treated
Hwy. 2 Counter Street, Kingston	1978	B 6 A 4	-33	B 13 A 13	No Change	DFC mix with 100% traprock aggregate	4 lane divided, 5% grade, sharp curve AADT 17 000
Hwy. 40 at Plank Road, Sarnia	1978	B 5 A 1	-80	B 7 A 3	-57	DFC mix with 100% steel slag aggregate	4 lane undivided AADT 7500 slight grade
Hwy. 2 & 4 at Wonderland Rd. London	1978	B 4 A 1	-75	B 12 A 9	-25	as above	4 lane undivided AADT 8750 slight grade
Hwy. 3 at Ridge Road,	1977	B 3 A -	-100	B 4 A 2	-50	C.M.I. Retexturing	4 lane undivided, 4% grade, AADT 6000, only 2 WB lanes "downgrade" treated
Total		B 35 A 10	-71	B 71 A 38	-46		

B and A designate number of accidents "Before" and "After" treatment



A' - Height of macro-projections (mm)
B' - Width of macro-projections (mm)
C' - Angularity of macro-projections (scale 0.0-3.0)
D' - Density of distribution of macro-projections (%)
E' - Harshness of macro-projection surfaces (scale 0.0-6.0)
F' - Harshness of micro-projections on matrix surfaces (scale 0.0-6.0)

FIGURE 1: Pavement Surface Profile

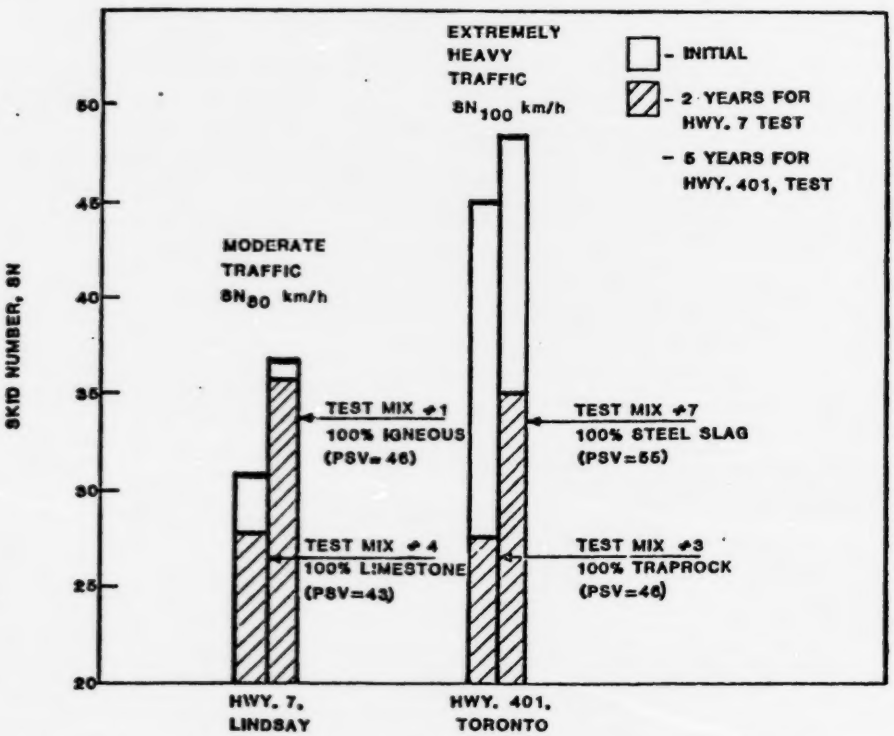


FIGURE 2: Effect of Polished Stone Value (PSV) on Skid Resistance Performance

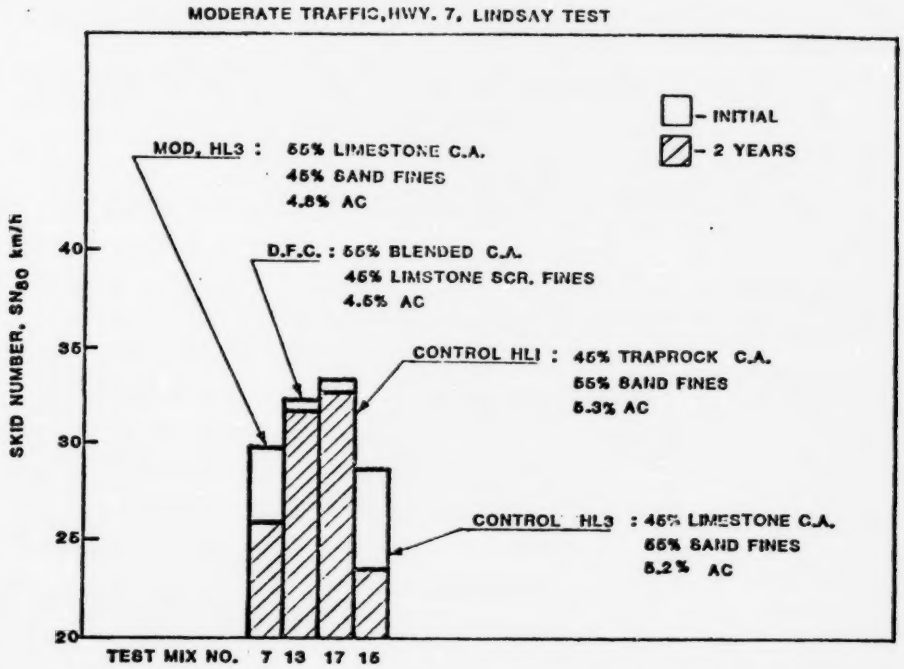


FIGURE 3: Skid Resistance Performance of Four Mixes With and Without Coarse Aggregate Blend

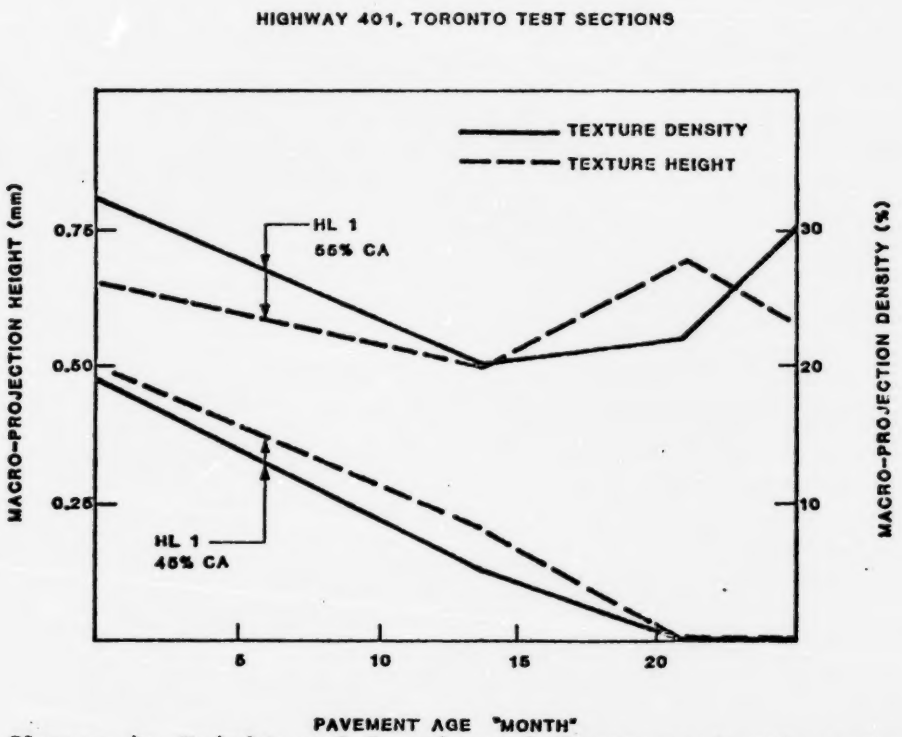


FIGURE 4: Change in Height and Density of Macro-Projections for 2 HL1 Mixes with Different Coarse Aggregate Content (Driving Lane; AADT 12 900; Commercial Vehicles 3740)

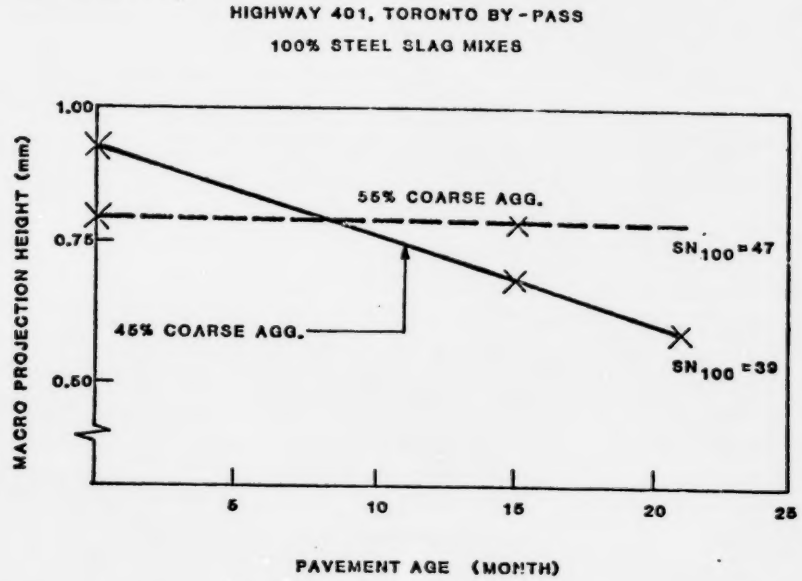


FIGURE 5: Change in Macro-Projection Height for Two Steel Slag Mixes with Different Coarse Aggregate Content

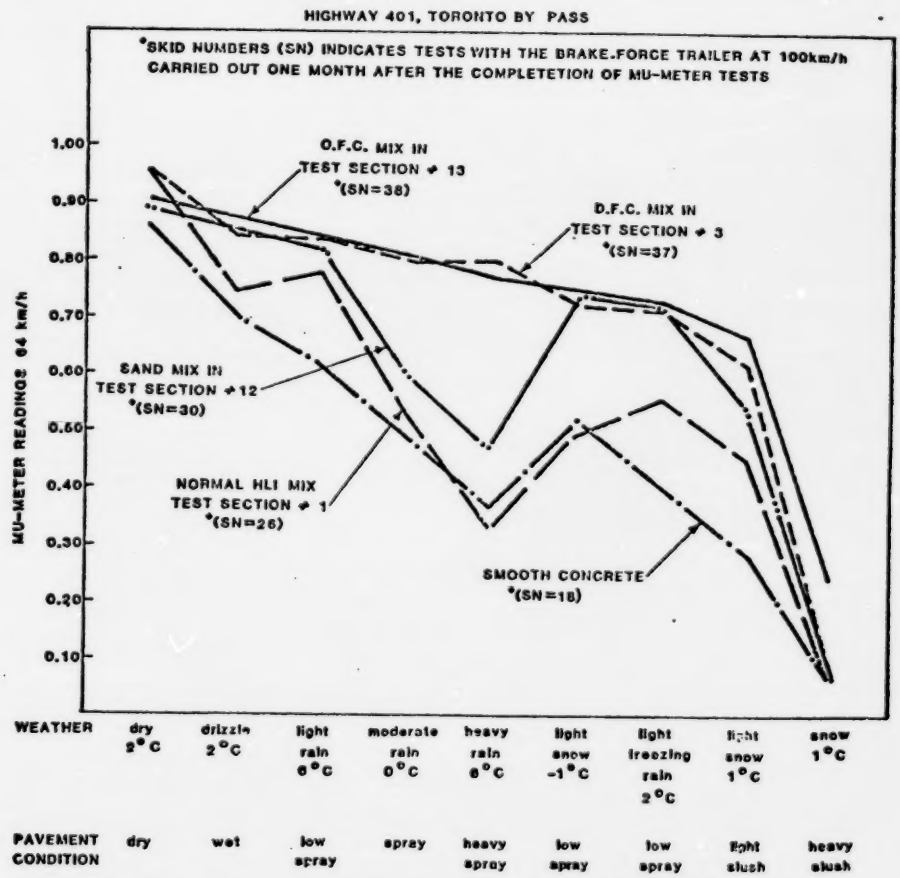


FIGURE 6: Skid Resistance Measurements in Different Weather Conditions Using the MU-Meter (Driving Lane) (After Reference 9)

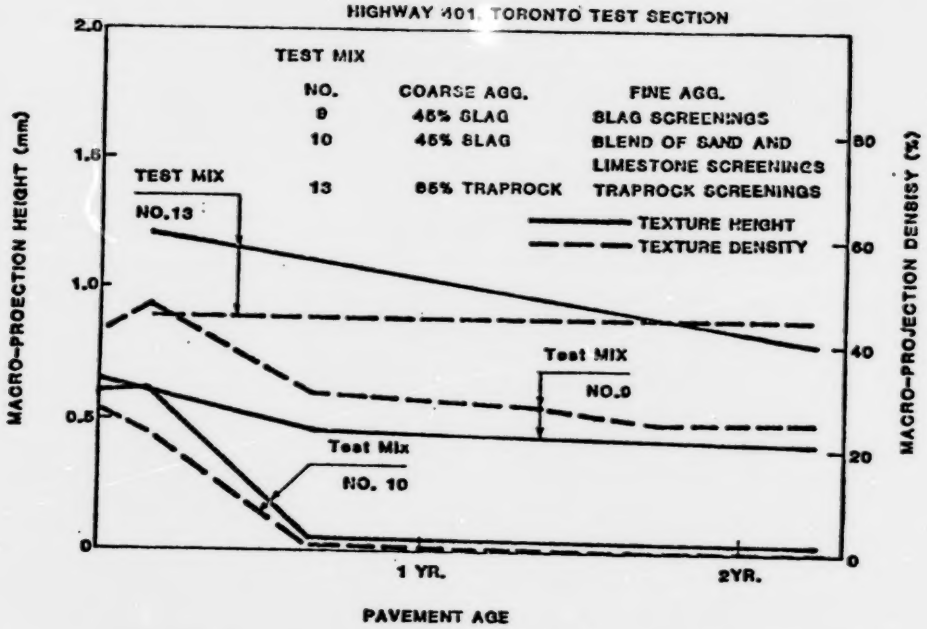


FIGURE 7: Change in Height and Density of Macro-Projections for Test Sections 9, 10 and 13. (Driving Lane) (After Reference 9)

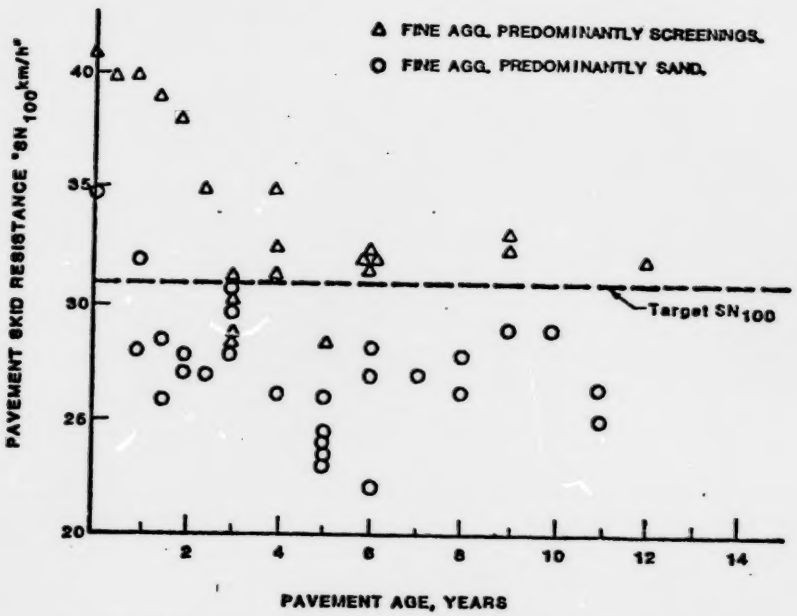


FIGURE 8: The 1976 HL1 Survey for Pavements with AADT >5000 Per Day Per Lane

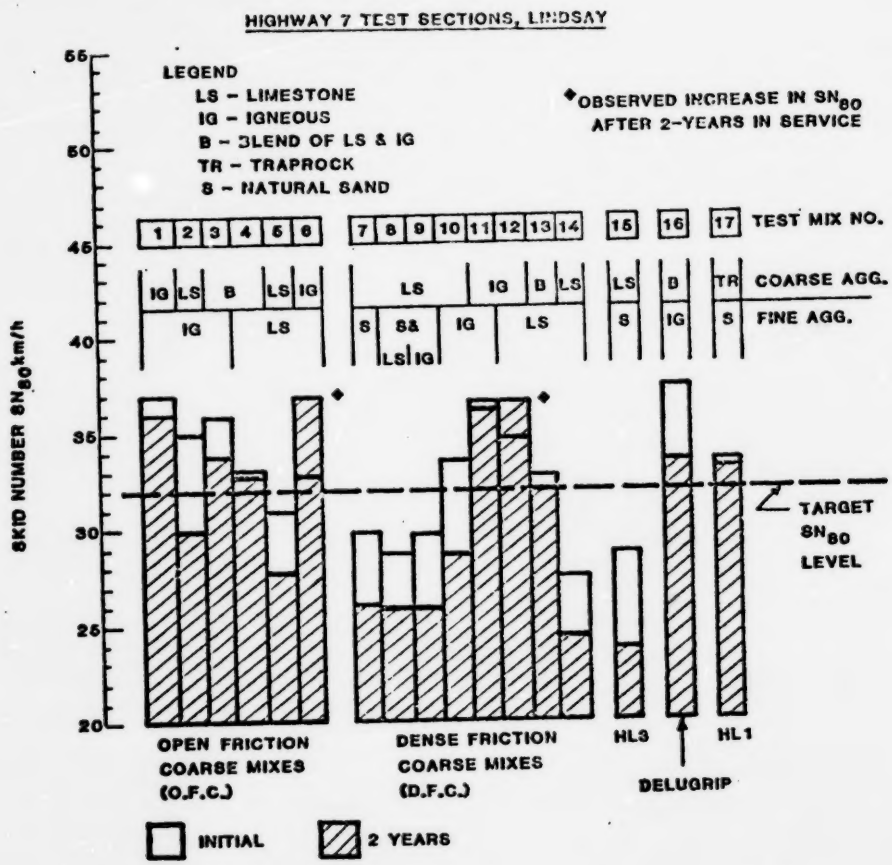


FIGURE 9: Initial and 2 Years' Skid Resistance Measurements, "Westbound"

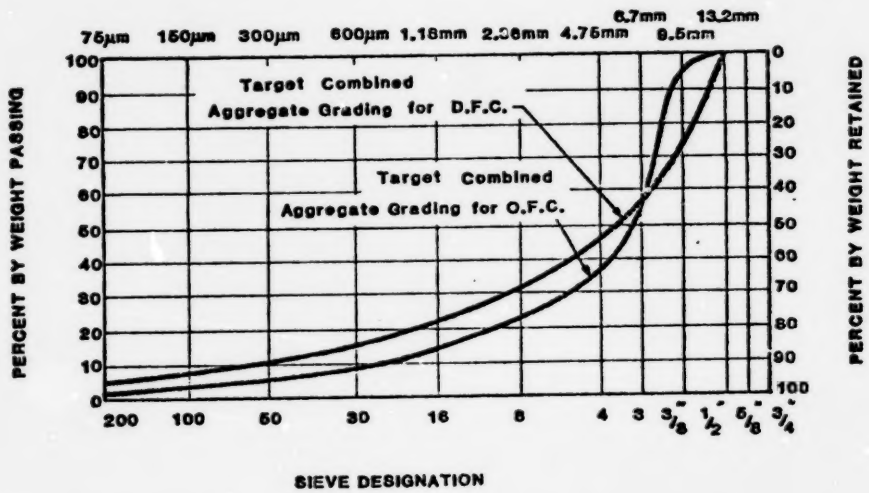

75µm 150µm 300µm 600µm 1.18mm 2.36mm 4.75mm 6.7mm 9.5mm 13.2mm
Target Combined Aggregate Grading for D.F.C.
Target Combined Aggregate Grading for O.F.C.
PERCENT BY WEIGHT PASSING
PERCENT BY WEIGHT RETAINED
SIEVE DESIGNATION

FIGURE 10: Target Aggregate Gradations For O.F.C. and D.F.C. Mixes

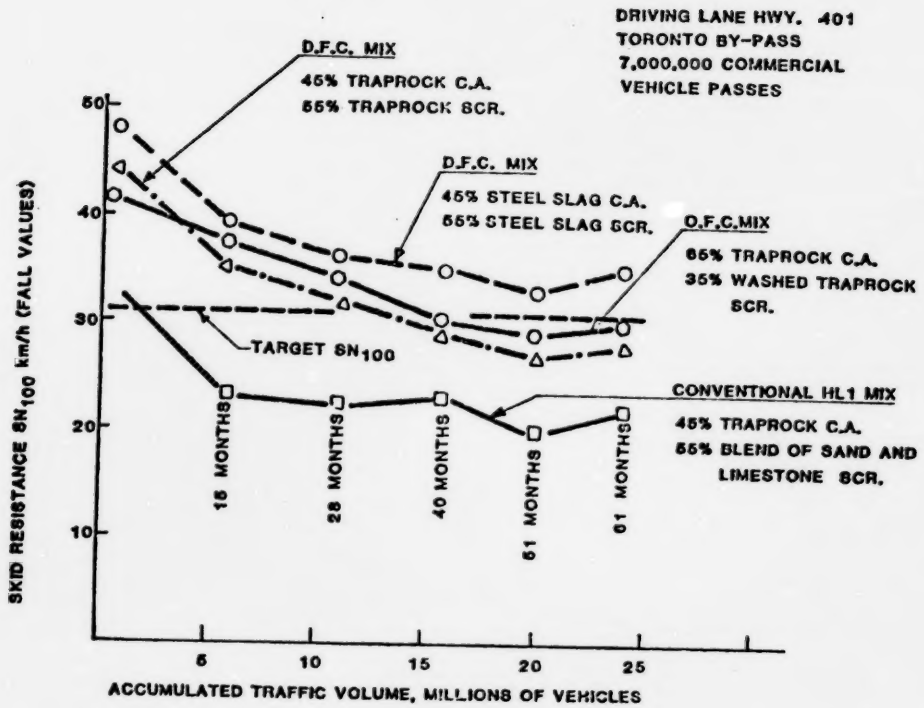


FIGURE 11: 5-Year Skid Performance History of O.F.C., D.F.C. and HL1 Mixes